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High Resolution Imaging of the Venus Night Side Using a Rockwell 128x128 HgCdTe Array

K.-W. Hodapp, W. Sinton
Institute for Astronomy, University of Hawaii

B. Ragent
NASA Ames

D. Allen
Anglo Australiàn Observatory

Abstract

The University of Hawaii operates an infrared camera with a 128x128 HgCdTe detector array on loan from JPL's HIRIS project. The characteristics of this camera system will be discussed. The infrared camera has been used to obtain images of the night side of Venus prior to and after inferior conjunction in 1988. The images confirm Allen and Crawford's (1984) discovery of bright features on the dark hemisphere of Venus visible in the H and K bands. Our images of these features are the best obtained to date. We derive a pseudo rotation period of 6.5 days for these features and 1.74 μm brightness temperatures between 425 K and 480 K. The features are produced by nonuniform absorption in the middle cloud layer (47-57 Km altitude) of thermal radiation from the lower Venus atmosphere (20-30 Km altitude). A more detailed analysis of the data is in progress.

I. INTRODUCTION

Allen and Crawford (1984) discovered bright features on the dark side of Venus at short infrared wavelengths, where thermal emission from the upper cloud layers of Venus would be too faint to be detected. Spectroscopic observations confirmed that this radiation is seen in two relatively narrow features at 1.74 μm and 2.3 μm wavelength, which are gaps in the absorption of CO_2 and H_2SO_4, the main absorbers in Venus atmosphere. In these spectral features, we see deeper into the hot atmosphere of Venus and the spatial structure arises from patchy absorption in optically thin clouds in the middle cloud layer (47-57 Km altitude) of Venus atmosphere. From measurements of the pseudo rotation period of these features, their association with the middle cloud layer can be confirmed. The features visible in the near-infrared are different from the structure seen in the UV from spacecraft, which is associated with the upper cloud level at 70 Km altitude. Groundbased near infrared observations can therefore make important contributions to our understanding of the dynamics of Venus atmosphere.

II. Infrared Array Characteristics

We were using a 128x128 HgCdTe Detector Array with a cutoff wavelength of 2.5μm, manufactured by the Rockwell International Science Center. The Detector Array is Indium bump bonded to a Reticon readout structure. This Detector array was made available to us by JPL's HIRIS project and, for HIRIS, was optimized for high read-out rates and high flux levels of an earth observing instrument in low earth orbit. Further, this device was optimized for the 150 K operating temperature expected in the passively cooled HIRIS instrument. For astronomical imaging, we use the device at a read-out rate of 4μs per pixel and achieve a read-noise of 2000 electrons. The peak quantum efficiency of the device itself is about 30 % in K, 20% in H and less than 10% in J at an operating temperature of 100 K. At lower temperatures, the Q.E. drops further, higher temperatures give a prohibitively large darkcurrent. The device shows large scale variations of the quantum efficiency of a factor 2 peak to peak across the chip. The dark current is dominated by luminescence in the multiplexer, reaching values as high as 4000 electrons per second near the output amplifier of the multiplexer and 500 electrons per second near the center of the device. The full well capacity is 800000 electrons, so that operation is always read noise limited. The device works linearly up to 70% of full well, above which a smooth transition to saturation occurs. The sensitivity of this detector array is clearly inferior to the performance achieved by other IR-arrays currently in use for astronomy. Its strength is the large format, allowing imaging of large fields of view without the need for extensive mosaicing.

III. The Infrared Camera System

The 128x128 array is mounted in an uplooking liquid nitrogen dewar for use at the 2.2 m and 0.6 m telescopes of the University of Hawaii (Fig. 1).

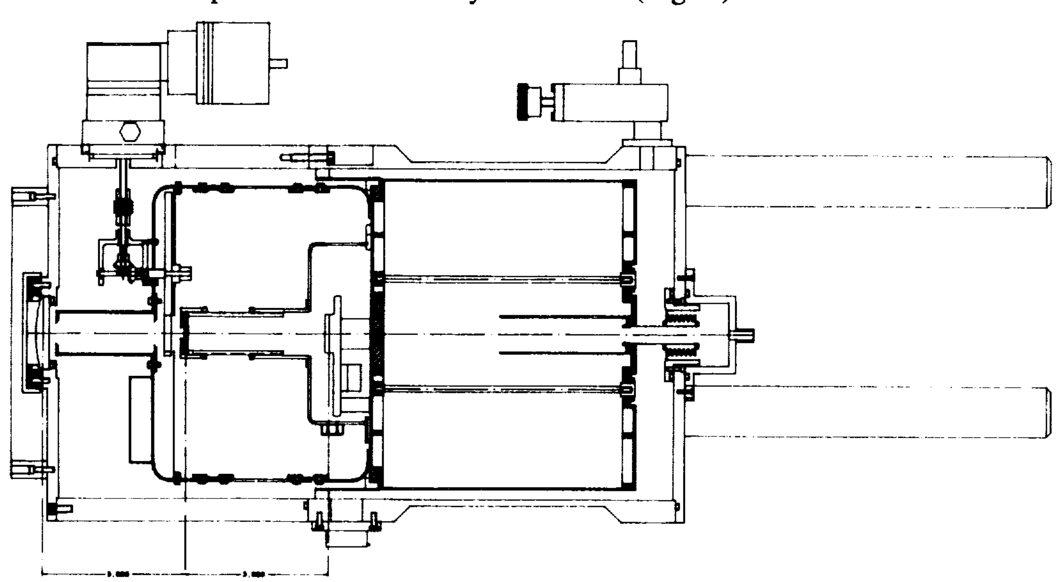

Fig. 1: Cross section through the UH Infrared Camera dewar. The dewar is an uplooking design with one LN_2 can. The optics are a straight refractive system with 1:1 reimaging.

The dewar is currently equipped with 1:1 reimaging optics consisting of a CaF_2 field lens and a biconvex ZnSe reimaging lens. The cold stop can easily be exchanged for use of the camera at different f-ratios ranging from f/5 (0.6 m) to f/35 (2.2 m). Up to now, the camera has only been used at the f/10 focus of the UH 2.2 m telescope with a plate scale of 0.55 "/pixel. The read-out electronics, developed by JPL (Kaki, Bailey, and Hagood, 1988), are mounted on the dewar. The 12 bit data words are transmitted via a high speed data link to a buffer board in a 12 MHz Compac 286 computer which contains sufficient memory to store a complete frame. This buffer board also controls the timing of the integrations. After reading the data from the buffer, the computer than handles data display, subtraction of sky frames, preliminary analysis and mass storage on disk and tape.

IV. Venus observations

As part of a collaboration lead by D. Crisp from JPL, involving UH, NOAO, and JPL's Table Mountain Observatory, we obtained images of the dark hemisphere of Venus approximately 2 weeks before and after inferior conjunction. A narrow band interference filter centered on the 1.74μm feature was custom made by Barr Associates and distributed to all participating observatories. This narrow band filter was used for most of the imaging work. However, we also obtained some images in broad band K, where these atmospheric features are also visible, and, for comparison, a few images at a wavelength of 1.57 μm, where no radiation can escape through the middle cloud layer. We stopped the UH 2.2 m telescope down to 0.55 m by an excentric full aperture mask mostly to keep sunlight from hitting the primary mirror of the telescope. As a positive side effect, we thereby created an unobstructed round telescope pupil eliminating the diffraction spikes of the secondary support and thus enhancing the image contrast. The excentric aperture was oriented such that sunlight would not reach the primary mirror during the daytime observations with Venus being only 20 degrees away from the sun. To further reduce straylight levels from the sunlit crescent of Venus, we placed a neutral density filter in the focal plane, covering the brightest parts of the crescent while leaving the dark side of Venus unobscured. In the end of May 1988, prior to inferior conjunction, with Venus east of the sun, we only obtained images under poor seeing conditions (2 arcsec or worse). In the end of June 1988, after inferior conjunction, with Venus in the morning sky, we obtained data of very high quality on five consecutive days. Each morning, the image quality was best in the first hour after sunrise (0.5 to 0.7 arcsec seeing), resulting in diffraction limited image quality (0.8 arcsec), and later deteriorated to typical mid-day seeing of 2 arcsec. The integration time in the narrow band filter was 30 sec and 2 sec in broad band K. Sky frames were taken 2 arcmin away from Venus and subtracted from the object frames. Skyflats were used for flatfield correction. Between individual images, the telescope was deliberately moved by a few arcseconds, in order to eliminate systematically bad pixels later. We typically took 20 frames per hour and coadded the individual images in 30 min bins, which is a short enough time interval to neglect motion of atmospheric features. For coaddition, the images were interpolated to 256x256 format, registered with a precision of one half the original pixel size, and coadded with the systematically bad pixels masked off.

V. Preliminary Results

The images, Fig. 2, show different atmospheric features on each day. Feature tracking gave a pseudo-rotation period of 6.5 +/- 0.5 days, corresponding to equatorial wind speeds of 68 m/s westwards. These wind speeds are consistent with Pioneer Venus and VEGA Balloon measurements for the middle cloud region at altitudes of 47-57 Km (Preston et al. 1986). It should be noted that the IR cloud features are not identical to those seen on the bright side of Venus in the UV. The UV features have a pseudo rotation period of 4 days and are associated with the highest cloud layer at about 70 Km altitude. At 1.74 μm, the brightness temperature of the brightest features is 480 K while the darkest features have brightness temperatures of 425 K. We do not interpret this as temperature nonuniformities in the middle cloud layer. Temperature nonuniformities of this magnitude in the middle cloud layer have never been observed by in situ measurements and would be difficult to understand theoretically. The brightness variations are interpreted as patchy, optically thin absorption in relatively cold clouds (300-320 K, Sagdeev et al., 1986) against the background of thermal radiation from lower layers of the atmosphere.

We plan to repeat observations of this kind during the next inferior conjunction of Venus, which fortunately coincides closely with the flyby of the Galileo probe at Venus. We hope to provide long time coverage of the atmospheric features on Venus while the spacecraft is expected to obtain images with much better resolution for a relatively short time.

We thank the staff of the UH 2.2 m telescope for their support during these observations. We thank E. Irwin, M. Wagner, and S. Massey for their help in designing and operating the UH Infrared Camera and G. Bailey and S. Kaki for providing the drive electronics for this device. The 128x128 infrared array is the result of work by the JPL Infrared Technology Group in support of the Spaceborne Imaging Spectrometer Project Office at JPL under funding by the NASA Office of Space Science and Application.

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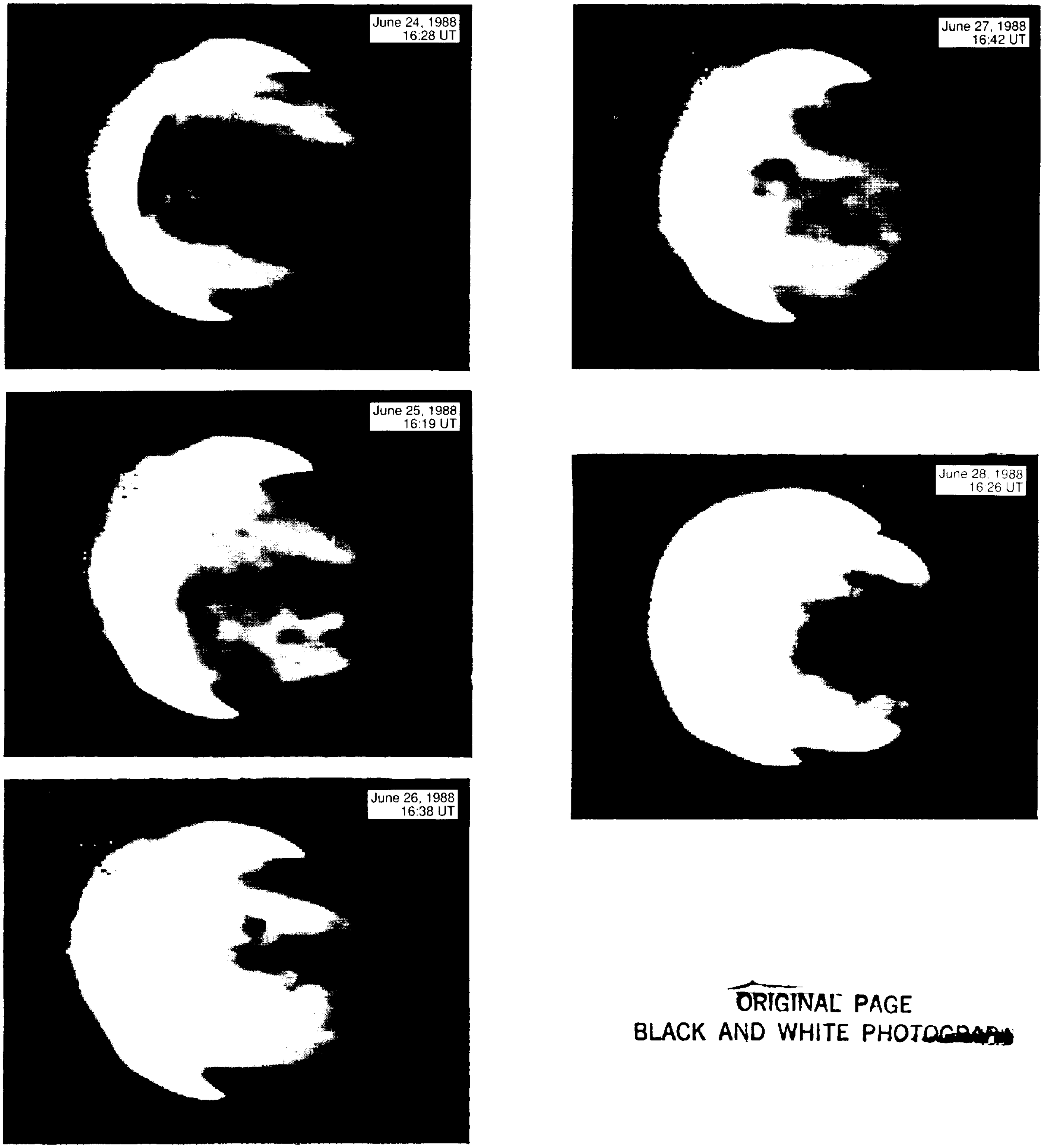

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Fig. 2 Images of the night hemisphere of Venus on five consecutive days. The images are the result of coadding up to 12 individual 30 sec exposures, sky subtracted and flatfielded images taken in a half hour interval. In the coaddition process, the images were individually aligned and systematically bad pixels have been removed. The observation dates given in Fig. 2 are the averages of the exposure dates of the individual frames coadded to produce the images.